CENTRIFUGAL PUMPS

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A pump is a hydraulic machine which converts mechanical energy into hydraulic energy or pressure energy.
A centrifugal pump is also known as a Rotodynamic pump or dynamic pressure pump. It works on the principle of centrifugal force. In this type of pump the liquid is subjected to whirling motion by the rotating impeller which is made of a number of backward curved vanes. The liquid enters this impeller at its center or the eye and gets discharged into the casing enclosing the outer edge of the impeller. The rise in the pressure head at any point/outlet of the impeller is Proportional to the square of the tangential velocity of the liquid at that point $(i.e, \alpha \frac{u^2}{2g})$. Hence at the outlet of the impeller where the radius is more the rise In pressure head will be more and the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a higher level. Generally centrifugal pumps are made of the radial flow type only. But there are also axial flow or propeller pumps which are particularly adopted for low heads.

Advantages of centrifugal pumps:-

1. Its initial cost is low
2. Efficiency is high.
3. Discharge is uniform and continuous
4. Installation and maintenance is easy.
5. It can run at high speeds,without the risk of separation of flow

Classification of centrifugal pumps

Centrifugal pumps may be classified
Into the following types

1.According to casing design
   a) Volute pump b) diffuser or turbine pump

2. According to number of impellers
   a) Single stage pump b) multistage or multi impeller pump

3. According to number of entrances
to the impeller:
   a) Single suction pump **(FOR FIGURES DOWNLOAD PRESENTATION)**
   b) Double suction pump

4. According to disposition of shaft
   a) Vertical shaft pump
   b) Horizontal shaft pump

5. According to liquid handled
   a) Semi open impeller
   b) Open impeller pump

6.According to specific speed

a) Low specific speed or radial flow impeller pump
b) Shrouded impeller
c) Medium specific speed or mixed flow impeller pump

c) High specific speed or axial flow type or propeller pump.

7. According to head (H)

- Low head if H<15m
- Medium head if 15<H<40m
- High head if H>40m

In the case of a volute pump a spiral casing is provided around the impeller. The water which leaves the vanes is directed to flow in the volute chamber circumferentially. The area of the volute chamber gradually increases in the direction flow. Thereby the velocity reduces and hence the pressure increases. As the water reaches the delivery pipe a considerable part of kinetic energy is converted into pressure energy. However, the eddies are not completely avoided , therefore some loss of energy takes place due to the continually increasing quantity of water through the volute chamber.
In the case of a diffuser pump the guide wheel containing a series of guide vanes or diffuser is the additional component. The diffuser blades which provides gradually enlarging passages surround the impeller periphery. They serve to augment the process of pressure built up that is normally achieved in the volute casing. Diffuser pumps are also called turbine pumps in view of their resemblance to a reaction turbine.
Multistage pumps and vertical shaft deep-well pumps fall under this category.
Centrifugal pumps can normally develop pressures upto 1000kpa (100m). If higher pressures are required there are three options.a) Increase of impeller diameter. b)Increase of Rpm. c)Use of two or more impellers in series.
The pump looks clumsy in option (a). The impeller material is heavily stressed in option (b) The third choice is the best and is generally adopted, the impellers which are usually of the same size are mounted on the same shaft. The unit is called a multistage pump. It discharges the same quantity of fluid as a single stage pump but the head developed is high. There are centrifugal pumps upto 54 stages. However, generally not more than 10 stages are required. In the case of the double suction impeller, two impellers are set back to back. The two suction eyes together reduce the intake. The two suction eyes together reduce the intake velocity reduce the risk of cavitations. Mixed flow type double suction axial flow pumps besides are capable of developing higher heads. For convenience of operation and maintenance, horizontal shaft settings are the preferred setups for centrifugal pumps. The exceptions are deep-well turbine pumps and axial flow pumps, these have vertical shafts. Restricted space conditions usually require a vertical shaft setting. Centrifugal impellers usually have vanes fitted between the shroudes or plate.

The crown plate has the suction eye and the base plate is mounted on a sleeve which is keyed to the shaft. An impeller without the crown plate is called the non-clog or semi-open impeller. In an open impeller both crown plate and the base plate are absent.
Only clear liquids, can be safely pumped by a shrouded impeller pump. The semi-open impeller is useful for pumping liquids containing suspended solids, such as sewage, molasses or paper pulp. The open-vane impeller pump is employed for dredging operations in harbours and rivers. Shrouded and semi open impellers may be made of cast

iron Or cast steel. Open vane impellers are usually made of forged steel. If the liquid pumped are corrosive, brass, bronze or gun metal are the best materials for making the impellers.

A radial flow impeller has small specific speeds (300 to 1000) & is suitable for discharging relatively small quantities of flow against high heads. The direction of flow at exit of the impeller is radial. The mixed flow type of impellers has a high specific speed (2500 to 5000), has large inlet diameter D and impeller width B to handle relatively large discharges against medium heads. The axial flow type or propeller impellers have the highest speed range (5000 to 10,000). They are capable of pumping large discharges against small heads. The specific speed of radial pump will be $10 < Ns < 80$, Axial pump $100 < Ns < 450$, Mixed flow pump $80 < Ns < 160$.

Components of a centrifugal pump

The main components of a centrifugal pump are:

i) Impeller ii) Casing iii) Suction pipe iv) Foot valve with strainer, v) Delivery pipe vi) Delivery valve.

Impeller is the rotating component of the pump. It is made up of a series of curved vanes. The impeller is mounted on the shaft connecting an electric motor.

Casing is an air tight chamber surrounding the impeller. The shape of the casing is designed in such a way that the kinetic energy of the impeller is gradually changed to potential energy. This is achieved by gradually increasing the area of cross section in the direction of flow.

Suction pipe It is the pipe connecting the pump to the sump, from where the liquid has to be lifted up.

Foot valve with strainer the foot valve is a non-return valve which permits the flow of the liquid from the sump towards the pump. In other words the foot valve opens only in the upward direction.

The strainer is a mesh surrounding the valve, it prevents the entry of debris and silt into the pump.

Delivery pipe is a pipe connected to the pump to the overhead tank.

Delivery valve is a valve which can regulate the flow of liquid from the pump.

Priming of a centrifugal pump

Priming is the process of filling the suction pipe, casing of the pump and the delivery pipe upto the delivery valve with the liquid to be pumped.

If priming is not done the pump cannot deliver the liquid due to the fact that the head generated by the Impeller will be in terms of meters of air which will be very small (because specific weight of air is very much smaller than that of water).

Priming of a centrifugal pump can be done by any one of the following methods:

i) Priming with suction/vacuum pump.
ii) Priming with a jet pump.
iii) Priming with separator.
iv) Automatic or self priming.

Heads on a centrifugal pump:

Suction head (hs): it is the vertical distance between the liquid level in the sump and the centre line of the pump. It is expressed as meters.

Delivery head (hd): It is the vertical distance between the centre line of the pump and the liquid level in the overhead tank or the supply point. It is expressed in meters.

Static head (Hs): It is the vertical difference between the liquid levels
In the overhead tank and the sump, when the pump is not working. It is expressed as meters.
Therefore, **HS= (hs+ hd)**
Friction head (hf): It is the sum of the head loss due to the friction in the suction and delivery pipes. The friction loss in both the pipes is calculated using the Darcy's equation, **hf=(fLV2/2gD)**.
Total head (H): It is the sum of the static head Hs, friction head (hf) and the velocity head in the delivery pipe (Vd 2/2g). Where, Vd=velocity in the delivery pipe.

$$\therefore H_m = \left(h_s + h_d + h_f + \frac{Vd^2}{2g} \right) - - - (1)$$

Manometric head(Hm): It is the total head developed by the pump. This head is slightly less than the head generated by the impeller due to some losses in the pump

$$\therefore H_m = H + \frac{Vs^2}{2g} - \frac{Vd^2}{2g}$$

Working of a centrifugal pump:

A centrifugal pump works on the principal that when a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and a centrifugal head is impressed which enables it to rise to a higher level.
Working operation of a centrifugal pump is explained in the following steps.

1) Close the delivery valve and prime the pump.
2) Start the motor connected to the pump shaft, this causes an increase in the impeller pressure.
3) Open the delivery valve gradually, so that the liquid starts flowing into the deliver pipe.
4) A partial vacuum is created at the eye of the centrifugal action, the liquid rushed from the sump to the pump due to pressure difference at the two ends fo the suction pipe.
5) As the impeller continues to run, move & more liquid is made available to the pump at its eye. Therefore impeller increases the energy of the liquid and delivers it to the reservoir.
6) While stopping the pump, the delivery valve should be closed first, otherwise there may be back flow from the reservoir.

It may be noted that a uniform velocity of flow is maintained in the delivery pipe. This is due to the special design of the casing. As the flow proceeds from the tongue of the casing to the delivery pipe, the area of the casing increases. There is a corresponding change in the quantity of the liquid from the impeller. Thus a uniform flow occurs in the delivery pipe.
Operation difficulties in centrifugal pumps

a) Pump fails to pump the fluid.

Cause	Remedial Measures
1) Improper priming due to leakage of foot valve or incomplete filling.	Repair or replace the foot valve, prime completely.
2) Head more than design head	Reduce the head or change the pump
3) Clogging of impeller, suction pipe or strainer	Clean the suspected part
4) Suction lift may be excessive	Reduce the height of pump above the sump
5) Speed more than design speed	Connect another prime mover of higher speed
6) Direction of rotation of impeller is wrong	Change the direction.

B) Pump does not give the required capacity

a) Leakage of air through the suction pipe or through the gland packing	Stop the leakage
b) Damage to some parts of the pump by wear & tear	Replace the damaged parts
c) Clogging of impeller passages	Clean the impeller

C) Pump has poor efficiency

a) Higher than design speed	**Reduce the speed**

b) Low head & higher discharge	**Reduce the discharge**
c) Impeller touching, the casing or improper alignment of shaft	**Carryout the necessary repair.**

D) Pump stops working

a) Air entry into suction pipe	Stop the pump, plug the leakage, reprime and start
b) Suction lift is high	Reduce the suction lift.

<u>Efficiencies of centrifugal pump</u>

<u>Manometric efficiency</u> (η): it is the ratio of the manometric head to the head actually generated by the impeller $n_{mano} = \left\{\frac{Hm}{Vw_2 u2/g}\right\} = \left\{\frac{gHm}{Vw_2 u_2}\right\}$

Mechanical efficiency(η **mech**): It is the ratio of the impeller power to the power of the motor or the prime mover. $\therefore n\,mech = \left\{\frac{\text{impeller power}}{\text{motor power}}\right\}$

Overall efficiency(ηo): It is the ratio of the work done by the pump in lifting water against gravity and friction in the pipes to the energy supplied by the motor.

$$\therefore n_o = \left\{\frac{\text{work done against gravity friction}}{\text{power of the prime mover or motor}}\right\}$$

Velocity Triangles of a Centrifugal Pump

Figure shows the inlet and outlet velocity triangles for a centrifugal pump.It may be noted that the inlet velocity triangle is radial,(velocity of whirl is zero at inlet or VW1 =0
Depending on the geometry of the blade at outlet it can be:
Forward:if the blade angle**$<90^0$,**Radial if Φ=90^0 , c) Backward if ¤ $> 90^0$

<u>Work done by the impeller of a centrifugal pump</u>:

Figure shows the velocity triangles at the inlet and outlet tips of a vane fixed to the impeller.

Let N=speed of the impeller in RPM
D= Diameter of the impeller at inlet

D=Diameter of the impeller at outlet
U_1 = Tangential velocity of the impeller at inlet $\pi D_1 N/60$
U_2= tangential velocity of the impeller at outlet $\pi D_2 N/60$
V_1=absolute velocity of the liquid at inlet
V_2= absolute velocity of the liquid at outlet.
Vf_1 & Vf_2 are the velocities of flow at inlet and outlet.
Vr_1 & Vr_2 Relative velocities at inlet and outlet
Vw_2 whirl velocity at outlet
~ angle made by V_1 with respect to the motion of the vane
– blade angle at inlet
¤ = blade angle at outlet

For a series of curved vanes the force exerted can be determined using the impulse momentum equation Work=force x distance.
similarly the work done/sec/unit weight of the liquid striking the vane= $\frac{1}{g}(Vw_2u_2 - Vw_1u_1)$

But for a centrifugal pump $V\omega_1 = 0$

Work done/sec/unit weight $\frac{Vw_2u_2}{g}$

And the work done/sec ¥ $\frac{Q}{g}Vw_2u_2 - (4)$

Where Q=volume of liquid flowing per second = Area x velocity of flow $Q = \pi D_2 B_2 Vf_2 - (5)$

In eq (5), B_2 is the width of the impeller at the outlet.

Design factors of centrifugal pumps:

a) Rim diameter D_2

Rim velocity or impeller velocity $u_2 = \frac{\pi D_2 N}{60} = K_u\sqrt{2gHm}$

Rim diameter $D_2 = \frac{60}{\pi N}\sqrt{2gKu}\sqrt{Hm} = \frac{85}{N}K_u\sqrt{Hm}$

Where N= speed in RPM Hm= manometric head, m

$K_u = U_2/\sqrt{2gHm} = \text{speed ratio}$

Value of varies from 0.95 to 1.8 depending on the specific speed.

b) Pipeline diameter:

The diameter of section and delivery pipes are designed to give velocities not exceeding 1.5 to 3 m/s on section and delivery sides.

c) Discharge (Q): the discharge or capacity of a centrifugal pump is given by
Where k =factor which accounts the reduction in flow area due to
To thickness of impeller vanes,
D2 =Rim diameter,B2 =Rim width,

Vf2=Constant velocity of flow through the impeller. Generally k=1 is considered.

PROBLEMS

1.A centrifugal pump running at 800 Rpm is working against a total head of 20.2 m. the external diameter of the impeller is 480mm and outlet width 60mm. If the valve angle at outlet is 40 and manometric efficiency is 70% determine
a)Absolute velocity of water leaving
b) Flow velocity at outlet The valve.
c) Angle made by the absolute velocity at outlet with the direction of motion at outlet.
d) Rate of flow through the pump.

Soln: velocity of valve at outlet $u_2 = \frac{®D_2N}{60} = \frac{®x0.48x800}{60} = 20.1m/s$

$manometric\ efficiency\ n_{mano} = \frac{gHm}{Vw_2u_2} \qquad ,0.70 = \frac{9.81x20.2}{Vw_2x20.1}, \quad Vw_2 = 14.08m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$

$\therefore Vf_2 = \tan 40^0 x(20.1 - 14.08) = 5.05m/s$

Absolute velocity of water leaving the valve V_2 is given by

$V_2 = \sqrt{Vf_2^2 + Vw_2^2} = \sqrt{5.05^2 + 14.08^2} = 14.96m/s$

Angle made by the absolute velocity at outlet with the direction of motion is given by

$\tan \quad = \frac{Vf_2}{Vw_2} = \frac{5.05}{14.08} = 0.3586 \qquad \therefore \quad = 19.7^0$

Rate of flow through the pump $Q = ®D_2B_2Vf_2 = ®x0.48x0.06x5.05 = 0.457m3/s$

2. A centrifugal pump impeller having external and internal diameter 480mm and 240mm respectively is running at 100 Rpm. The rate of flow through the pump is 0.0576 m3/s and velocity of flow is constant and equal to 2.4m/s. the diameter of the section and delivery pipes are 180mm and 120mm respectively and section and delivery heads are 6.2m(abs) and 30.2m(abs) of water respectively. If the power required to drive the pump is 23.3KW and the outlet vane angle is 45 determine. a) inlet vane angle b) Overall efficiency c) manometric efficiency of the pump

Soln: tangential velocity or impeller velocity at inlet

$u_1 = \frac{®D_1N}{60} = \frac{®x0.24x1000}{60} = 12.56m/s$

From the inlet velocity triangle $\tan ¤ = \frac{Vf_1}{u_1} = \frac{2.41}{12.56} = 0.191$

$\therefore ¯ = 10.8^0$ $(inlet\ vane\ angle)$

Overall efficiency $n_0 = \frac{rQHm}{P} = \frac{9.81x0.05xHm}{23.3}$ $\therefore n_0 = 0.02387Hm$ (1)

$$but, Hm = \left\{ \left(Z_2 + \frac{p_2}{r} + \frac{V_2^2}{2g} \right) - \left(Z_1 + \frac{p_1}{r} + \frac{V_1^2}{2g} \right) \right\}$$

$$where, V_2 = V_d = \frac{4Q}{®d_d^2} = \frac{4x0.0567}{®x0.12^2} = 5.01m/s$$

$$where, V_2 = V_s = \frac{4Q}{®d_s^2} = \frac{4x0.0567}{®x0.18^2} = 2.23m/s$$

$let\ Z_1 = Z_2$ i.e pump inlet and outlet are at same level.

$\frac{p_1}{r} = h_s = 6.2m(abs)$ $\frac{p_2}{r} = h_d = 30.2m(abs)$

$$\therefore Hm = \left\{ \left(30.2 + \frac{5.01^2}{2x9.81} \right) - \left(6.2 + \frac{2.23^2}{2x9.81} \right) \right\} = 25.03m$$

n_0, overall efficiency of pump

=0.02387x25.03=0.597=59.7%

Velocity of the impeller at outlet $u_2 = \frac{®D_2N}{60} = \frac{®x0.48x1000}{60} = 25.13m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$, $\tan 45^0 = \frac{2.4}{25.13 - Vw_2}$,

$Vw_2 = 22.73m/s$

Manometric efficiency $n_{mano} = \frac{gHm}{Vw_2u_2} = \frac{9.81x25.03}{22.73x25.13} = 0.43 = 43\%$

3. It is required to deliver 0.048m3/s of water to a height of 24m through a 150mm diameter and 120m long pipe by a centrifugal pump. If the overall Efficiency of the pump is 75% and co efficient of friction f=0.01 for the pipe line. Find the power required to drive the pump.

Soln: velocity of water pipe $V_s = V_d = V = \frac{4Q}{®d^2} = \frac{4x0.048}{®x0.15^2} = 2.7m/s$

Overall efficiency $n_0 = \frac{rQHm}{P}$ $0.75 = \frac{9.81x0.048x27.37}{P}$, $P = 17.2KW$

4. The impeller of a centrifugal pump is of 300mm diameter and 50mm width at the periphery and has blades whose tip angle incline backwards 60 from the radius. The pump deliveries 17m3/min of water and the impeller rotates at 1000
Rpm. Assuming that the pump is design to admit radically. calculate

a)Speed and direction of water as it leaves the impeller,
b)Torque exerted by the impeller on water c) Shaft power required

d) Lift of the pump. Take mechanical=95% and hydraulic efficiency=75%

Soln: tangential velocity of the impeller at the outlet

$$u_2 = \frac{®D_2N}{60} = \frac{®x0.3x1000}{60} = 15.71m/s$$

From continuity equation $Q = ®D_2B_2Vf_2$, $\quad Vf_2 = \frac{0.2833}{®x0.3x0.05} = 6m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$

$$Vw_2 = \left(u_2 - \frac{Vf_2}{\tan ¤}\right) = \left(15.71 - \frac{6}{\tan 60^0}\right) = 12.24m/s$$

Absolute velocity of water at the outlet tip of the impeller

$$V_2 = \sqrt{Vf_2^{\,2} + Vw_2^2} = \sqrt{6^2 + 12.24^2} \qquad V_2 = 13.63\, m/s\ (magnitude)$$

$$= \tan^{-1}\left(\frac{Vf_2}{Vw_2}\right) = \tan^{-1}\left(\frac{6}{12.24}\right) = 26.5^0$$

Torque exerted by the impeller on water

$$T = \frac{rQ}{g}(Vw_2R_2) = \frac{9.81x0.2833}{9.81}x(12.24x\frac{0.3}{2}) \ = 0.52KN\ m$$

Shaft power (P) impeller or rotor power $\frac{2®NT}{60} = \frac{2®x1000x0.52}{60} = 54.45KW$

But, mechanical efficiency $n_{mech} = \frac{impeller\ power}{shaft\ power}$ $i.e,\ 0.95 = \frac{54.45}{P} \quad P = 57.31KW$

<u>Lift of the pump</u>

Impeller power=r(Q+q)H
Where r=sp wt of water=9.81 KN/m3
H =ideal head=(theoretical head-hyd losses)
Q=leakage of water m3/s
Neglecting leakages q we have

54.45=9.81x0.2833xH
Or h =19.59m

We know, hydraulic efficiency $n_h = \frac{Actual\ head\ or\ lift}{ideal\ head}$

$$Actual\ hft = n_h xideal\ head(H_i) \quad 0.70x19.59 = 13.71m\ of\ water$$

5. The following data relate to a centrifugal pump. Diameter of the impeller at inlet & outlet =180mm and 360mm respectively. width of impeller at inlet and outlet=144mm & 72mm respectively. rate of flow through the pump=17.28lps. Speed of the impeller = 1500 Rpm. Vane angle at outlet=45 water enters the impeller radially at inlet neglecting losses through the impeller. Find the pressure rise in the impeller.

Soln: velocity of flow at inlet $Vf_1 = \frac{Q}{\text{®}D_1B_1} = \frac{0.01728}{\text{®}x0.18x0.0144}$

Velocity of flow at outlet $Vf_2 = \frac{Q}{\text{®}D_2B_2} = \frac{0.01728}{\text{®}x0.36x0.0072} = 2.12m/s$

Tangential velocity of impeller at outlet $u_2 = \frac{\text{®}D_2N}{60} = \frac{\text{®}x0.36x1500}{60} = 28.27m/s$

Pressure rise in the impeller is given by the equation $= \frac{1}{2g}\left\{Vf_1^2 + u_2^2 - Vf_2^2 \cos ec^2 \text{¤}\right\}$

$$= \frac{1}{2x9.81}\left\{2.12^2 + 28.27^2 - 2.12^2 x \cos ec^2 45^0\right\}$$

6. A centrifugal pump delivers water at the rate of 1800 lpm,to a height of 20m, Through a 0.1m, dia, 80m. long pipe. Find the power required to drive the pump, if the overall efficiency is 65%, and Darcy's friction factor=0.02.

Soln. Discharge Q=1800 lpm=0.03 cumecs.
Delivery head hd =20m
Dia of delivery pipe dd=0.1m
Length of delivery pipe $l_d = 80m$
Overall efficiency $n_0 = 0.65$ $f = 0.02$

Total head $\mathbf{H} = \mathbf{h_s} + \mathbf{h_d} + \mathbf{h_{fs}} + \mathbf{h_{fd}} + \frac{\mathbf{Vd^2}}{\mathbf{2g}}$

So this prob $h_s = 0$ $h_{fs} = 0$ (details are not given)

$$\therefore \mathbf{H} = \mathbf{h_d} + \mathbf{h_{fd}} + \frac{\mathbf{Vd^2}}{\mathbf{2g}}$$

$$= \left\{\mathbf{20} + \frac{\mathbf{8x0.02x80x0.03^2}}{\mathbf{9.81x\pi^2x0.1^5}} + \left(\frac{\mathbf{4x0.03}}{\mathbf{\pi x0.1^2}}\right)^{\mathbf{2}} \mathbf{x} \frac{\mathbf{1}}{\mathbf{9.81x2}}\right\} \qquad H=32.65m$$

Output of the pump=$\text{¥}QH = 9.81x0.03x32.65 = 9.6kw$

But overall efficieny $\text{¦}_0 = \frac{Output\ of\ the\ pump}{power\ require\ to\ drive\ the\ pump}$

Power required to drive the pump = 9.6/0.65=14.8kw

7. A centrifugal pump is required to deliver 280 ltrs of water per second against a head of 16m, when running at 800rpm. If the blades of the impeller are radial at inlet and velocity of flow is constant and equal to 2m/sec, find the proportions of the pump. Assume overall efficiency as 80% and ratio of breadth to diameter at outlet as 0.1

Soln: the inlet and outlet velocity triangles will be as shown
From continuity equation $Q = \text{®}D_2B_2Vf_2$ $0.28 = \text{®}x0.1xD_2x2$

$\therefore D_2 = 0.67m(\textit{diameter of the impeller at outlet})$

$B_2 = 0.1x0.67 = 0.067m = 6.7cm$ (Width of the impeller at outlet).

$n_{mano} = \dfrac{gHm}{Vw_2u_2} \quad 0.8 = \dfrac{9.81x16}{Vw_2u_2}$

$Vw_2u_2 = 196.2 \quad (i) \quad but \;\; u_2 = \dfrac{®D_2N}{60} = \dfrac{®x0.67x800}{60} = 28.1m/s$

From eq (i) $Vw_2x2.81 = 196.2 \;\; or \;\; Vw_2 = 6.99m/s$

From the outlet velocity triangle $\tan ¤ = \dfrac{Vf_2}{u_2 - Vw_2} = \left\{\dfrac{2}{28.1 - 6.99}\right\} = 0.0947$

$\therefore ¤ = 5.41^0$ (Blade angle at outlet) $\tan \quad = \dfrac{Vf_2}{Vw_2} = \dfrac{2}{6.99} = 0.286 \quad \therefore \quad = 16^0$

8. The following data refer to a centrifugal pump static head = 40m, suction height 5m, dia of suction and delivery pipes = 0.1m, loss of head in suction pipe = 2m, loss of head in delivery pipe = 8m, impeller dia at outlet =0.4m, impeller breadth at outlet 25mm.blades occupy 10% of the outlet area, speed 1200rpm. Exit angle of blade = 1500 with the tangent, Manometric efficiency = 80%, overall efficiency = 70%. Find the power required to drive the pump and what pressures will be indicated by the gauges mounted on the suction and delivery sides.

Soln: Outlet vane angle $\therefore ¤ = 180 - 150 = 30^0$

Delivery head $h_d = (H_s - h_s) = (40 - 5) = 35m$

Head on the pump H=40+2+8=50m

From the outlet velocity triangle $\tan ¤ = \left\{\dfrac{Vf_2}{u_2 - Vw_2}\right\}$

$where, u_2 = \dfrac{®D_2N}{60} = \dfrac{®x0.4x1200}{60} = 25.13m/s$

Also from the equation $n_{mano} = \dfrac{gHm}{Vw_2u_2} \qquad Vw_2 = \dfrac{9.81x50}{25.13x0.8} = 24.4m/s$

$Vf_2 = (u_2 - Vw_2)\tan ¤ = (25.13 - 24.4)\tan 30^0 \;\; Vf_2 = 0.422m/s$

$disch\arg e, Q = K®D_2B_2Vf_2 = 0.9x®x0.4x0.025x0.422 = 0.0119m3/s$

Power given to the liquid P=rQH $= 9.81x0.0119x50 = 5.85KW$

Power required to drive the pump $= \dfrac{P}{¦_0} = \dfrac{5.85}{0.7} = 8.36kw$

Pressure gauge reading on the suction side = hs+hfs $= 5 + 2 = 7m \textit{ of water}$

Pressure gauge reading on the delivery side = $h_d + h_{fd} = 35 + 8 = 43m$

9. Following data were obtained from a centrifugal pump in a laboratory. Pressure gauge reading on the suction side 15cm of mercury, pressure gauge reading on the delivery side 170kN/m2. quantity of water raised by the pump =7.5kN/min. vertical height difference

between the gauges =500mm. Total input to the pump = 6.5kw.Find the efficiency of the pump.

Soln: Suction head hs=0.15x13.5=2.04m of water
Delivery head hd=170/9.81=17.34m of water. Head on the pump = (hs+hd+x+Vd2/2g)
Since the dia of the delivery pipe is not given, velocity in the delivery pipe is ignored.
$\therefore H = (2.04 + 17.34 + 5)) = 19.88m$

Discharge from the pump $= \frac{7.5}{60} x \frac{1}{9.81} = 0.0127 m^3 / \sec$

Output of the pump¥$QH = 9.81x0.127x19.88 = 2.48kw$

Efficiency of the pump =2.48/6.5=0.382.=38.2%

10. The internal and external diameters of the impeller of a centrifugal pump are 40cms and 80cms respectively. The pump is running at 1200rpm. The vane angles at inlet and outlet are 200 and 300 respectively. Water enters the impeller radially and velocity of flow is constant. Determine the workdone by the impeller per kN of water.

$$so\ln : u_1 = \frac{®D_1 N}{60} = \frac{®x0.4x1200}{60} = 25.13m/s$$

$$u_2 = \frac{®D_1 N}{60} = \frac{®x0.8x1200}{60} = 50.26m/s$$

From the inlet velocity triangle $\tan^{-} = \frac{Vf_1}{u_1}$

$\therefore Vf_1 = Vf_2 = 25.13 \tan 20^0 = 9.15m/s$

From the outlet velocity triangle
tanΦ=Vf2/(u2-vw2)=9.15/(50.26-vw2)
or , Vw2=34.41m/s
Work done/sec=1/g(vw2 u2) =34.41*50.26/9.81=176.3kn-m/s/kn

11. The impeller of a centrifugal pump runs at 90 Rpm and has vaves inclined at 120 to the direction of motion at exit. If the manometric head is 20m and manometric efficiency is 75% Vane angles at inlet. Take the velocity of flow as 2.5m/s, throughout and the diameter of the impeller at exit as twice that at inlet.

a) Diameter of the impeller at exit.

Soln: From the definition of manometric efficiency $¦_{mano} = gHm / Vw_2 u_2$

$$Vw_2 u_2 = \frac{9.81x20}{0.75} = 261.6 \quad (i)$$

From the outlet velocity triangle $(u_2 - Vw_2) = \frac{Vf_2}{\tan 60^0} = \frac{2.5}{\tan 60^0} = 1.44 \quad Vw_2 = (u_2 - 1.44)$

Substituting the value $Vw_2, (u_2 - 1.44) u_2 = 261.6 = 16.9m/s \quad but\ u_2 = \frac{®D_2 N}{60}$

$D_2 = \frac{60x16.9}{\text{®}x90} = 3.59m/s$

further $u_1 = \frac{u_2}{2} = \frac{16.9}{2} = 8.45m/s$

From the inlet velocity triangle $\tan\text{¯} = \frac{Vf_1}{u_1} = \frac{2.5}{8.45} = 0.2959$

$\therefore \text{¯} = 16.48^0 (Inlet\, Vane\ Angle)$

12. A centrifugal pump delivers 250lps against a head of 20m. When the impeller rotates at 1500rpm. If the mano metric efficiency is 75% and the loss of head in the pump is 0.033V22, where V2 is the absolute velocity at exit. The diameter of the impeller

a) The blade angle at exit

Take the width of the impeller at exit as 0.4D where D is the diameter of the impeller

Soln: $u_2 = \frac{\text{®}D_2N}{60} = \frac{\text{®}xDx1500}{60} = 78.5D \quad Vf_1 = \frac{Q}{\text{®}DB} = \frac{0.25}{\text{®}xDx0.4D} = \frac{0.199}{D^2}$

From the definition of manometric efficiency $n_{mano} = \frac{gHm}{Vw_2u_2}$

$\therefore \frac{Vw_2u_2}{g} = \frac{Hm}{n_{mano}} = \frac{20}{0.75} = 26.7$

But, manometric head=(workdone the impeller –losses in the pump)

$\therefore 0.033V_2^2 = 26.7 - 20 \quad V_2 = 14.25m/s$

From eq (i) and (ii)

$\therefore \frac{Vw_2x78.5D}{9.81} = 26.7 \; or \; Vw_2 = \frac{3.34}{D}$

From the outlet velocity triangle $Vf_2^2 + Vw_2^2 = V_1^2$

$\left(\frac{0.199}{D^2}\right)^2 + \left(\frac{3.34}{D}\right)^2 = 14.2^2$

Solving by trial and error D=0.242 m

$\therefore u_2 = 78.5D = 78.5x0.242 = 19m/s \quad Vf_2 = \frac{0.199}{D^2} = \frac{0.199}{0.242^2} = 3.4m/s$

$Vw_2 = \frac{3.34}{D} = \frac{3.34}{0.242} = 13.8m/s \quad \tan\text{¤} = \frac{Vf_2}{u_2 - Vw_2} = \left(\frac{3.4}{19-13.8}\right) = 0.654$

$\text{¤} = 33.2^0 \; (outlet\ vane\ angle)$

13. A centrifugal pump lifts water against a static head of 40m. The section and delivery pipes are each 15cm in diameter. The head loss in the section and delivery pipes are respectively 2.20m and 7.5m. The impeller is 40cm in diameter and 2.5cm wide at the month. It revolves at 1200Rpm and the vane angle at exit is 30. if the manometric efficiency is 80%. Calculate the discharge.

Soln: $\frac{\text{®}}{4}x0.15^2xV_s = Q$ $\quad V_s$ = velocity in the section pipe

$\therefore V_s = 56.6Q \ (i) \quad (®D_2B_2)Vf_2 = Q \qquad (®x0.4x0.025)Vf_2 = Q \quad Vf_2 = 31.8Q \ (ii)$

From eq (a) and (b) $Vf_2 = 0.56V_s \ (iii)$

$$now\, u_2 = \frac{®D_2N}{60} = \frac{®x0.4x1200}{60} = 25.1m/s$$

$$H_m = (h_s + h_d) + hf_s + hf_d + \frac{Vs^2}{2g} \quad H_m = 40 + 2.2 + 7.5 + \frac{Vs^2}{2g} \quad H_m = 49.7 + \frac{Vs^2}{2g} \ (iv)$$

$$n_{mano} = \frac{gHm}{Vw_2u_2}$$

$$0.8 = \left\{9.81x\left[49.7 + \frac{Vs^2}{2g}\right] / \left(25.1 - 0.56V_s x \cot 30^0\right) x25.1\right\} \qquad V_s^2 + 39V_s - 33 = 0$$

$\therefore V_s = 0.83m/s \ (velocity\ in\ the\ section\ pipe)$

$$\& \ Q = \frac{0.83}{56.6} = 0.0147m3/s \ (Discharge)$$

14. A centrifugal pump has a total lift of 15m and is placed 2m above the water level in the sump. The velocity of water in the delivery pipe is 2m/s. If the radial velocity of flow through the wheel is 3m/s and tangent to the vane at exit makes an angle of 60 find (a) the velocity of water at exit (b) the guide vane angle © the pressure at the impeller exit. Neglect friction and other losses.

Soln: total head $= 15 + \frac{Vd^2}{2g} = \left(15 + \frac{2^2}{19.62}\right) = 15.20m$

From the outlet velocity triangle $Vw_2 = u_2 - \frac{Vf_2}{\tan 60^0} = u_2 - \frac{3}{\sqrt{3}} = (u_2 - 1.73)$

$$now, \frac{Vw_2u_2}{g} = Hm \quad i.e\ \frac{(u_2 - 1.73)u_2}{9.81} = 15.2 \quad u_2 = 13.12m/s$$

$$Vw_2 = (13.12 - 1.73) = 11.39m/s$$

$$V_2 = \sqrt{Vw_2^2 + Vf_2^2} = \sqrt{11.39^2 + 3^2} = 11.78 \qquad \tan \quad = \frac{Vf_2}{Vw_2} = \frac{3}{11.39} = 0.263$$

$= 14.75^0$ (guide vane angle at exist)

Applying bernoulli's equation to points on the sump water surface and impeller exit, taking datum at the sump level. $\frac{p_2}{r} + \frac{V_2^2}{2g} + 2 = 0 + 0 + Hm$

$\therefore \frac{p_2}{r} = \left(15.2 - 2 - \frac{11.78^2}{19.62}\right)$ =6.13m of water (gauge)

15. The axis of a centrifugal pump is 2.5m above the water level in the sump and the static lift from the pump centre is 35m. The friction losses in the section and delivery Pipes are of 15cm diameter. The impeller is 30cm diameter and 2cm wide at outlet and its speed is 1800 Rpm. The blade angle at exit is 30. calculate the shaft power to be supplied and the discharge delivered. Take n mano=75% and n o=70%. If the guages are

connected to the section and delivery sides of the pump determine the pressure indicated by these guages.

Soln:

$$u_2 = \frac{®D_2N}{60} = \frac{®x0.3x1800}{60} = 28.3m/s$$

$$Vw_2 = (u_2 - Vf_2 \cot 30^0) = (28.3 - 1.732Vf_2) \qquad Vf_2 = \left(\frac{Q}{®x0.3x0.02}\right) = 53Q$$

$$Vw_2 = (28.3 - 1.732x53Q) = (28.3 - 92Q) \qquad H_m = 2.5 + 35 + 1 + 8 + \frac{Vd^2}{2g} = (46.5 + \frac{Vd^2}{2g})$$

$$\therefore H_m = 46.5 + 163Q^2 \qquad \therefore H_m = n_{mano} x \frac{Vw_2 u_2}{g}$$

$$\therefore 46.5 + 163Q^2 = \left\{\frac{0.75x(28.3 - 92Q)x28.3}{9.81}\right\}$$

Solving the quadratic equation Q=0.0725 m3/s

$$shaft\ power = \frac{rQHm}{n_0} = \frac{9.81x0.0725x(46.5 + 163x0.0725^2)}{0.70} = 48.12KW$$

$$also, \frac{Ps}{r} = -h_s - \frac{Vs^2}{2g} - hf_s = -\left\{2.5 + 163x0.0725^2 + 1\right\} = -4.36m$$

$$= 42.77KN/m^2\ (vaccum)$$

Pressure at the exit is given by $P_1 = (P_s + rHm) = \left[-42.77 + (46.5 + 163x0.0725^2)x9.81\right]$

$$\therefore P_1 = 421.8\ KN/m^2$$

16. A centrifugal pump is required to handle a slurry consisting of sand and water (s=1.08). If the Quantity of slurry to be pumped is 250lps against a head of 15m. Find the power required by the pump, taking its overall efficiency as 70%. Find also the pressure developed by the pump.

Soln: power required $= \frac{rQH}{n_0} = \frac{(1.08x9.81)x0.25x15}{0.70} = 56.76KW$

Pressure developed rH=9.81x1.08x15 $= 159Kpa\ or\ KN/m^2$

17. Design centrifugal pump impeller for the following conditions, speed=800Rpm, head =8m hydraulic efficiency =88%, overall efficiency=80% shaft input =20KW, peripheral coefficient=1.15 ratio of inlet to outlet diameter=0.6, ratio of width to diameter at outlet=0.15, flow area blocked by vanes=6%, find to be pumped is gasoline of specific gravity=0.80.

Soln: $u_2 = K_u\sqrt{2gHm} = 1.15x\sqrt{19.62x8} = 14.4m/s$

$$u_1 = 0.6u_2 = 0.6x14.4 = 8.64m/s$$

$outer\ diameter\ D_2 = \frac{60u_2}{®N} = \frac{60x14.4}{®x800} = 0.344m$ =34.4cm

Inlet or eye diameter $D_1 = 0.6D_1 = 0.6x34.4$

$\therefore D_1 = 20.6cm$

$B_2 = 0.15\, D_2 = 0.15x34.4 = 5.16cm$

Shaft power $\therefore 20 = \dfrac{9.81x0.8xQx8}{0.8}$

$Q \;= 0.255m3/s$

$$Vf_1 = Vf_2 = \frac{Q}{K®D_2B_2} = \left\{\frac{0.255}{0.94x®x0.344x0.0516}\right\}$$

$= 4.86m/s$

$$Vw_2 = \frac{gHm}{n_h u_2} = \frac{9.81x8}{0.88x14.4} = 6.19m/s$$

From the inlet velocity triangle $-= \tan^{-1}\left(\dfrac{Vf_1}{u_1}\right) = \tan^{-1}\left(\dfrac{4.86}{8.64}\right) = 29.4^0$

From the outlet velocity triangle $= \tan^{-1}\left(\dfrac{Vf_2}{u_2 - Vw_2}\right) = \tan^{-1}\left(\dfrac{4.86}{14.4 - 6.19}\right) \therefore = 30.6^0$

18. Determine the manometric and overall efficiencies of a centrifugal pump from the following data. Head =22m discharge=160lps liquid pumped=brine of specific gravity=1.18 speed=1200 Rpm diameter=30cm, width=5cm shaft power=55KW, vane angle at outlet =35

Soln:

$$u_2 = \frac{®D_2N}{60} = \frac{®x0.3x1200}{60} = 18.85m/s \qquad Vf_2 = \frac{Q}{®D_2B_2} = \frac{0.16}{®x0.3x0.05} = 3.4m/s$$

From the outlet velocity triangle

$$Vw_2 = (u_2 - \frac{Vf_2}{\tan -}) = (18.85 - \frac{3.4}{\tan 35^0}) = 14m/s$$

$$n_{mano} = \frac{gHm}{Vw_2u_2} = \frac{9.81x22}{14x18.85} = 0.818 = 81.8\%$$

$$overall\ efficiency\ n_0 = \frac{rQHm}{shaft\ \ power} = \left\{\frac{1.18x9.81x0.16x22}{55}\right\} = 0.741 = 74.1\%$$

<u>Minimum speed for starting a centrifugal pump</u>.

When a centrifugal pump is started , Will start delivering liquid only if the pressure rise in the impeller is more than or equal to the manometric head (H mano). In other words, there will be no flow of liquid until the speed of the pump is such that the required centrifugal head caused by the centrifugal force or rotating water when the impeller is rotating, but there is no flow i.e flow will commence only if $\frac{u_2^2 - u_1^2}{2g} \geq H_m$

For minimum starting speed, we must have $\frac{u_2^2 - u_1^2}{2g} \geq H_m$

We know $n_{mano} = \frac{gHm}{Vw_2 u_2}$ $\quad n_{mano} = \frac{gHm}{Vw_2 u_2}$

$$u_1 = \frac{®D_1 N}{60}, u_2 = \frac{®D_2 N}{60} \quad (3)$$

Substituting eqn (2) & (3) in eq (1)

$$\frac{1}{2g}\left\{\left(\frac{®D_2 N}{60}\right)^2 - \left(\frac{®D_1 N}{60}\right)^2\right\} = n_{mano} x \frac{Vw_2}{g} x \frac{®D_2 N}{60}$$

Dividing both the sides by $\frac{®N}{60g}$

And simplifying $\frac{®N}{120}\left(D_2^2 - D_1^2\right) = n_{mano} x Vw_2 D_2$

$$\therefore N = N_{\min} = \left(\frac{120 n_{mano} x Vw_2 x D_2}{®\,(D_2^2 - D_1^2)}\right)$$

Problems

1. The impeller of a centrifugal pump is 1.0m in diameter and 0.1m wide. It delivers 2m3/s of water through a height of 45m while running at 600 Rpm. If the blades are curved backward and the outlet angle is 30 calculate the manometric efficiency and the power required to run the pump. Estimate the minimum speed to start the pump if the impeller diameter at inlet is 0.6m

Soln: from continuity equation $Q = ®D_2 B_2 Vf_2$

$$Vf_2 = velocity\ of\ \ flow\ at\ outlet\ = \frac{2}{®x1x0.1} = 6.37 m/s$$

$$u_1 = \frac{®D_1 N}{60} = \frac{®x0.6x600}{60} = 18.85 m/s$$

$$u_2 = \frac{®D_2 N}{60} = \frac{®x1x600}{60} = 31.42 m/s$$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$

$$\tan 30^0 = \frac{6.37}{31.42 - Vw_2}\ or Vw_2 = 20.38 m/s$$

Manometric efficiency $n_{mano} = \frac{gHm}{Vw_2 u_2} = \frac{9.81x45}{20.38x31.42} = 0.689$

Power given to the liquid=rQHm=9.81x2x45=882.9KW

Minimum starting speed

$$N_{\min} = \left\{ \frac{120Vw_2 D_2 n_{mano}}{® (D_2^2 - D_1^2)} \right\} = \left\{ \frac{120x20.38x1x0.689}{® (1^2 - 0.6^2)} \right\} = 838RPm \approx 840Rpm$$

2. The diameters of the impeller of a centrifugal pump at inlet and outlet are 40cm and 80cm respectively. Determine the minimum starting Speed if it works against a head of 25m.

Soln: for minimum starting speed $\frac{u_2^2 - u_1^2}{2g} \geq Hm$

$$i.e, \frac{1}{2g} \left\{ \frac{®^2 D_2^2 N^2}{60^2} - \frac{®^2 D_1^2 N^2}{60^2} \right\} \geq Hm$$

$$\frac{1}{2x9.81} x \frac{®^2 x N^2}{60^2} \left\{ 0.8^2 - 0.4^2 \right\} = 25$$

Solving for N, N=610.5Rpm (Min starting speed)

Multistage centrifugal pumps

When a centrifugal pump consist of two or more impellers the pump is know as a multistage centrifugal pump.

The important functions of a multistage centrifugal pump are;

(i) To produce high head (pumps in series)

(ii) To deliver or discharge large quantities of a liquid (pumps in parallel)

Pumps in parallel: it is an arrangement made by mounting a number of impellers on the shaft of a motor as shown. Such an arrangement is useful when the liquid has to be pumped to large heights keeping the discharge constant. If, Hm is the head developed by one impeller n= number of impellers. Then, nxHm= total head developed by the pump Q=discharge through the pump.

Pumps in parallel: it is an arrangement made by connecting a number of pumps in parallel as shown. Such an arrangement is useful when a large quantity of liquid is to be pumped to a particular height.

If Q=discharge from one pump

N=identical number pumps.

Then, nxQ= total discharge delivered by the pump Hm is the head developed by the pump.

Problems:

1.A three stage centrifugal pump has an impeller of 40cm diameter and 2.5cm thickness at outlet. The vanes are curved back at the outlet at 30 and reduce the circumfarential area by 15% the manometric efficiency is 85%and overall efficiency is 75% determine the

head generated by the pump when running at 1200 Rpm and discharging 0.06m 3/s. find the power required to drive the pump.

Soln: from the continuity equation $Q = K®D_2B_2Vf_2$
K= total percentage area available for flow=(1-0.15)=0.85
$\therefore 0.06 = 0.85x®x0.4x0.025xVf_2 \quad Vf_2 = 2.25m/s$

$$u_2 = \frac{®D_2N}{60} = \frac{®x0.4x1200}{60} = 25.13m/s$$

From outlet velocity triangle $\tan ¤ = \dfrac{Vf_2}{u_2 - Vw_2}$

$$\therefore Vw_2 = \left\{25.13 - \frac{2.25}{\tan 30^0}\right\} = 21.23m/s$$

Manometric efficiency $n_{mano} = \dfrac{gHm}{Vw_2u_2}$

$$or\ H_m = \frac{21.23x25.13x0.85}{9.81} = 46.23m$$

Total head developed by the pump H=3Hm=3x46.23=138.7m
Output of the pump P=rQh=9.81x0.06x138.7=81.64KW
Power required to drive the pump $\dfrac{P}{n_0} = \dfrac{81.64}{0.75} = 108.85KW$

2. Find the number of impellers and the diameter of each impeller required for a multistage centrifugal pump to lift 80lps of water against a total head of 225m. Assume speed=1500Rpm, approximate specific speed=600 peripheral Coefficient=0.96 and overall efficiency=80% what is the shaft input required

Soln: specific speed $N_s = \dfrac{N\sqrt{Q}}{H_m^{\frac{3}{4}}}$

$$\therefore H_m = \left\{\frac{1500x\sqrt{80}}{600}\right\}^{\frac{4}{3}} = 63m\ (head\ \ per\ stage)$$

$$number\ of\ \ stages = \frac{225}{63} = 3.57\ or\ 4$$

Diameter of each impeller $= \dfrac{85}{N}K_u\sqrt{H_m}$

$$= \frac{85}{1500}x0.96x\sqrt{63} = 0.432m$$

$$shaft\ input = \frac{rQHm}{n_0} = \frac{9.81x0.08x225}{0.8}220.7KW$$

<u>Specific speed (Ns)</u>

The specific speed of a centrifugal pump is defined as the speed of a geometrically similar pump which would deliver unit quantity (1m 3/s) against a unit head (1m). It is denoted by Ns.
Specific speed is a characterstic of pumps which can be used as a basis for comparing the performance of different pumps.
Expression for specific speed(Ns)
From continuity equation Q=Area x velocity of flow $= \text{®}DBxV_f \ i.e$,
Where, D & B are diameter and width of pump impeller.

$but\ B \sim D$

$\therefore Q \sim D^2 Vf \qquad (ii)$

Tangential velocity u is given by

$u = \frac{\text{®}DN}{60} \ \ or \ \ u \sim DN \qquad (iii)$

$also\ V_f = K\sqrt{2gHm} \ \ or \ \ Vf \sim \sqrt{Hm}$ --(iv)

Comparing eq (iii) and (iv) $\therefore u \sim Vf \sim \sqrt{H_m} \quad (v)$

$or\ DN \sim \sqrt{Hm} \qquad D \sim \frac{\sqrt{Hm}}{N} \quad (vi)$

Substituting the value of D from eq (vi) in eq (ii) $Q \sim \left\{ \frac{\sqrt{Hm}}{N} \right\}^2 x\sqrt{Hm}$

$i.e\ Q \sim \frac{Hm^{\frac{3}{2}}}{N^2} \qquad or\ Q = K\frac{Hm^{\frac{3}{2}}}{N^2} \quad (vii)$

In order to eliminate the value of K substitute Q=1m 3/s, H=1m and N=Ns in eq(vii)

$\therefore 1 = Kx\frac{1^{\frac{3}{2}}}{N_s^2}\ or\ K = N_s^2 \quad (viii)$

<u>Substituting $K = N_s^2$ in eq(vii)</u>

$Q = N_s^2 \frac{Hm^{\frac{3}{2}}}{N}\ or\ N_s = \left(\frac{N\sqrt{Q}}{Hm^{\frac{3}{4}}} \right) \quad (ix)$

The range of specific speeds Ns for different types of pumps are:
Radial flow = 10 to 30(slow speed)
Radial flow = 30 to 50 (Medium speed)
Radial flow = 50 to 80 (high speed)
Mixed flow = 80 to 160 (screw type)
Propeller type = 160 to 500 (or axial flow)

<u>Problems:</u>

1. Calculate the specific speed of a centrifugal pump running at 1000 Rpm. The diameter of the impeller is 30 cm and its width 6cm. The pump delivers 120lps with a manometric efficiency of 85%. The effective outlet blade angle is 30. neglect the thickness of blades.

Soln: $u_2 = \dfrac{®D_2N}{60} = \dfrac{®x0.3x1000}{60} = 15.7m/s$

$$Vf_1 = \frac{Q}{area\ of\ \ flow} = \frac{0.12}{®x0.3x0.06} = 2.12m/s$$

From the outlet velocity triangle

$$Vw_2 = \left\{u_2 - \frac{Vf_2}{\tan ¤}\right\} = \left\{15.7 - \frac{2.12}{\tan 30^0}\right\} = 12.03m/s$$

From the definition of manometric efficiency $n_{mano} = \dfrac{gHm}{Vw_2u_2} = \dfrac{9.81xHm}{12.03x15.7} = 0.85$

$\therefore Hm = 16.36\ m/s$

Specific speed $N_s = \dfrac{N\sqrt{Q}}{Hm^{\frac{3}{4}}} = \left\{\dfrac{1000x\sqrt{0.12}}{(16.36)^{\frac{3}{4}}}\right\} = 42.6$

Performance of centrifugal pumps:

Generally a centrifugal pump is worked under its maximum efficiency conditions, however when the pump is run at conditions other than this it performs differently. In order to predict the behaviour of the pump under varying conditions of speed, discharge and head, full scale tests are usually performed. The results of these tests are plotted in the form of characteristic curves. These curves are very useful for predicting the performance of pumps under different conditions of speed, discharge and head. Following four types of characteristic curves are usually prepared for a centrifugal pump.

a. Main characteristic.
b. Operating characteristics
c. Constant efficiency or Muschel characteristic.
d. Constant head an constant discharge curves.

Main Characteristic: the pump is operated a particular constant speed, discharge is varied by adjusting the delivery valve. Manometric head Hm and the shaft power P are measured for each discharge. The overall efficiency is then calculated. The curves are plotted between Hm & Q, P & Q, & Q. A set of similar curves are plotted by running the pump at different speeds. They will be as shown.

b. Operating characteristic: The curves are obtained by running the pump at the design speed, which is also the driving speed of the motor. The design discharge and head are obtained from the corresponding Curves, where the efficiency is maximum as shown.

c. Constant efficiency curves: The constant efficiency curves are obtained from the main characteristic curves. The line of maximum efficiency is obtained by joining the points of the maximum curvature of the constant efficiency lines. These curves are useful in Determining the range of operation of a pump.

d. Constant head and constant discharge curves: If the pump has a variable speed, the plots between Q and N and that between Hm and N may be obtained by varying the speed. In the first case Hm is kept constant & in the second Q is kept contant.

Model testing of centrifugal pumps: Models of centrifugal pumps are usually tested to predict the performance of prototypes. The discharge (Q) delivered by a centrifugal pump depends upon the Manometric head (Hm), impeller dia (D), power (P), speed (N), viscosity (μ), density (P) and acceleration due to gravity (g).

$Q = ¤\{H_m, D, P, N, «, p, g\}$

By dimensions analysis, it can be shown that $\left[\frac{Q}{ND^3}\right] = ¤\left\{\left[\frac{hH_m}{N^2D^2}\right], \left[\frac{«}{eND^2}\right], \left[\frac{P}{D^5N^3P}\right]\right\}$

Hence, for completely dynamic similarly to exist between the pump model and its prototype, assuming that g,P & « are the same in the model & the proto type.

$$\left[\frac{Q}{ND^3}\right]_P = \left[\frac{Q}{ND^3}\right]_m ; = \left[\frac{H_m}{N^2D^2}\right] = \left[\frac{Hm}{N^2D^2}\right]m$$

$$\left[\frac{1}{ND^2}\right]_P = \left[\frac{1}{ND^3}\right]_m ; = \left[\frac{P}{D^5N^3}\right]_P = \left[\frac{P}{D^5N^3}\right]m$$

As long as the flow in the model is turbulent $\left[\frac{1}{ND^2}\right]_P = \left[\frac{1}{ND^2}\right]$ can be ignored (i.e equality of Reynold's number). Moreover, the specific speed of the model should be equal to that of the prototype. i.e. $\left[\frac{N\sqrt{Q}}{H_{m4}^{\;3}}\right]_P = \left[\frac{N\sqrt{Q}}{H^{\frac{3}{4}}{}_m}\right]_m$

Problems:

1) A half scale model of a centrifugal pump runs at 7000Rpm and has an impeller of 15cm, diameter. If it delivers 0.04 cumes of water under a head of 40m. Calculate the speed and the head of the prototype assuming the same efficiency, what is the specific speed of the pump if the discharge in the prototype is 0.08m3/sec

Soln:

$$\frac{Q_P}{N_P D^{\frac{3}{P}}} = \frac{Q}{N_m D_m^{\;3}}$$

$$\therefore \frac{N_P}{N_m} = \frac{Q_P}{Q_m} x \left(\frac{D_m}{D_P}\right)^3$$

$$or \quad N_P = 7000X\,\frac{0.08}{0.04} x \left(\frac{1}{2}\right)^3 = 1750Rpm$$

$$\frac{H_m}{N_P^{\;2} D_P^{\;2}} = \frac{(H_m)_m}{N_m^{\;2} D_m^{\;2}} \quad \therefore (H_m)_P = \frac{N_P^{\;2}}{N_m^{\;2}} x \frac{D_P^{\;2}}{D_m^{\;2}} x (H_m)_m = \left(\frac{7000}{1750}\right)^2 x(2^2)x(40) = 10m$$

$$Specific\ Speed\ N_S = \frac{N\sqrt{Q}}{H_m^{\frac{3}{4}}} = \frac{1750X\sqrt{0.08}}{(10)^{\frac{3}{4}}} = 88$$

2. Two geometrically similar pumps are running at the same speed of 1000Rpm. One pump has an impeller diameter of 300mm and lifts water at the rate of 0.02m3/s against a head of 15m. Determine the head and impeller diameter of the other pump to deliver half the discharge.

Solution:

$$\left[\frac{N\sqrt{Q}}{H_m^{\frac{3}{4}}}\right]1 = \left[\frac{N\sqrt{Q}}{H_m^{\frac{3}{4}}}\right]_2$$

$$i.e.\quad \frac{1000x\sqrt{0.02}}{(15)^{\frac{3}{4}}} = \frac{1000x\sqrt{0.01}}{(H_m)^{\frac{3}{4}}_2}$$

$$\therefore (H_m)_2 = 9.45m$$

$$\left[\frac{\sqrt{H_m}}{DN}\right]_1 = \left[\frac{\sqrt{H_m}}{DN}\right]_2$$

$$i.e.\quad \frac{\sqrt{15}}{0.3x1000} = \frac{\sqrt{9.45}}{D_2 x\sqrt{1000}} \qquad \therefore D_2 = 0.238M = 238mm$$

CAVITATION IN PUMPS

Cavitation begins to appear in centrifugal pumps when the pressure at the section falls below the vapour pressure of the liquid. The cavitation in a pump can be noted by a sudden drop in efficiency head and power requirement.

The harmful effects of cavtation are:

a) Pitting and erosion of surfaceSudden drop in head, efficiency and power delivered to the fluid.
b) Noise and vibration produced by the collapse of bubbles.

The factors which facilitate outlet of Cavtation are as follows:

a) Restricted section b) High runner speed
b) Too high specific speed for optimum design parameters
c) Too high temperature of the following liquid.

ADDITIONAL QUESTIONS (VTU QUESTION PAPERS)

1.Explain with neat sketch the working of single stage centrifugal pump.

2.Find the power required to drive centrifugal pump which delivers 0.02m3/s of water to a height of 30m through a 10cm diameter 90m long pipe. The overall Efficiency of the pump is 70% and friction factor=0.036 (Aug 2000)

3. A centrifugal pump discharges 0.03 cumces to a height of 18.25m through a 100mm diameter, 90m long pipe overall efficiency is 75% f=0.04. find the power required to drive the pump (Aug 2001,2002, feb 2006)

4. Explain breifly

(i) Single and multistage pumps
(ii) Priming of pumps
(iii) Manometric head
(iv) Efficiencies of centrifugal (Aug 2001)

(v) 5. What is priming in centrifugal pump? Derive an expression
For the minimum speed for starting a centrifugal pump. (mar 2001)
6. Explain pumps in series and pumps in parallel (mar 2001,july 2006)
7. A centrifugal pump with 1.2m dia runs at 200 Rpm and pumps 1880lps at an average lift 6m. The vane angle at exit with the tangent of impeller is 26 and the
Radial flow velocity is 2.5 m/s. determine the manometric efficiency and the least speed to start the pump against a head of 6m. The inner diameter of impeller is 0.6m (march 2001)
8. Define the terms
(i) Section head
(ii) Delivery head
(iii) Static head
(iv) Manometric head (feb 2002)
9. Show that the pressure rise in the impeller of a centrifugal pump is given by

$$\frac{P_2 - P_1}{r} = \frac{1}{2g}\left\{Vf_1^2 - V_2^2 - Vf_2^2 \cos ec^2 \text{¤}\right\}$$

10. Define
a) Manometric head
b) Manometric efficiency
c) Mechanical efficiency
d) Overall efficiency (Feb 2002, july 2006)

11. Differentiate Manometric efficiency and volumetric efficiency
Static head and manometric head (feb 2003)

12. A centrifugal pump has a outer diameter equal to two times the inner diameter and running at 1000 Rpm works against a head of 40m velocity of flow through the impeller is constant and is equal To 2.5 m/s . The vanes are set back at an angle of 40 at outlet. If the outer diameter of the impeller is 0.5m and width is 0.05m determine
- Vane angle at inlet
- Work done/see by impeller
- Manometric efficiency (feb2003)

13. What is priming? Why is it necessary? Mention any two Priming devices (feb 2003)
14. Obtain an expression for the minimum speed for starting a centrifugal pump (feb 2003)
15.A centrifugal pump discharge 0.15 m3/s of water against a head of 12.5m the speed of the impeller being 600 Rpm. The outer and inner diameter of impeller are 500mm and 250mm respectively. and the vanes are bent back at 35 to the tangent at exit. If area of flow is 0.07m from inlet to outlet calculate
- Manometric efficiency of the pump
- Vane angle at inlet
- Loss of head at inlet to impeller when the discharge is reduced by 40% without changing the speed (feb 2004)

16. Explain the losses and efficiencies of centrifugal pump (aug 2004)

17. Derive the expression $Hm = h_d + h_s + hf_s + hf_d + \frac{Vd^2}{2g}$

For a centrifugal pump where Hm = manometric head h_d =delivery head

h_s =suction head

Friction loss in section and delivery
Pipes

= velocity in delivery pipe (aug 2004)

18. A centrifugal pump of the radial type delivers 5000lpm against a total head of 38m, when running at a speed of 1450 Rpm. If the outer diameter of the impeller is 30cm & its width at the outer periphery is 1.30cm. Find the vane angle at Exit. Assume manometric efficiency as 80% (Aug 2004)
19. Define specific speed of a centrifugal pump derive and expression for the same (aug 2005)
20. A single stage centrifugal pump with impeller diameter of 30cm rotates at 2000 Rpm and lifts 3 m3/s of water to a height of 30m
With an efficiency of 75%. Find the number of stages and diameter of each impeller of a similar multistage pump to lift 5 m3/s to a height of 200m. When rotating at 1500 Rpm. (aug 2005)
21. Distinguish between pumps in series and parallel (feb 2006)
22. Differentiate the following
a) Pump and turbine
b) Section head and delivery head
c) Manometric and overall efficiency
d) Single stage and multi stage pump (feb 2005)
23. With a neat sketch explain the various components of a centrifugal pump. Why is it necessary to prime the centrifugal pump (aug 2005, feb 2006 jan 2007)
24. A centrifugal pump delivers 3000lpm of water against a head of 24m. The blades are curved backwards at 30 to the tangent at exit and the pump runs at 1500 Rpm assuming a flow velocity of 2.4m/s as constant throughout the machine. A manometric efficiency of 80% and inner diameter one half of the outer diameter. Find the blade angle at inlet and power expended by the pump (aug 2005)
25. The diameter of centrifugal pump at inlet and outlet are 30cm and 60cm respectively. Determine the minimum starting speed of the pump if it works against head of 30m.
26. The internal and external diameter of the impeller of a centrifugal pump are 200mm and 400mm respectively. The pump is running at 1200Rpm . The vane angle of the impeller at inlet and outlet are 20 and 30 respectively. The water enters the impeller radially and velocity of flow is constant. Determine the work done by the impeller per unit height of water.
27. A centrifugal pump delivers 30lps to a height of 18m through a 100mm diameter 100m long pipe. If the overall efficiency is 75% find the power required to drive the pump. Use the expression for $hf = \frac{FlV^2}{2gd}$ & $f = 0.01$ head loss due to friction in the pipe

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